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Indian Standard

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METHODS FOR ASSESSMENT OF CIRCULARITY ERROR FROM POLAR GRAPHS OBTAINED BY USING STYLUS-TYPE FORM-MEASURING INSTRUMENT

1. Scope — Covers the numerical assessment of circularity error from the circularity (polar) graph of the measured profile obtained using stylus-type instruments. Methods which are commonly used in workshops for measurement of circularity errors are given along with their limitations in Appendix A.

2. Definition — For the purpose of this standard, the following definitions shall apply.

2.1 *Ideal Circularity* — The condition when all the points on the profile are equidistant from a common centre.

2.2 *Measured Profile* — A quantitative representation of the profile, obtained by means of instruments.

2.3 *Circularity Error of the Measured Profile (on Polar Graphs)* — The difference between the largest and smallest radii of two concentric circles, that just enclose the profile.

3. Instruments Used for Circularity Measurement — The instruments of the stylus type shall be used for obtaining the circularity graph of the measured profile. These instruments shall comply with the following requirements.

3.1 *Stylus Tip* — The stylus tip shall be of either spherical or hatchet form as shown in Fig. 1. The choice of the stylus tip depends upon the surface characteristics of the part under examination.

3.1.1 The shapes and radii of the stylus used for tracing the profile of a nominal circular section, are important because, the trace of such a profile may be considerably distorted by an improper choice of the stylus.

3.2 *Stylus Tip Radius* — The choice of the stylus tip radius depends upon the circumferential lay characteristics of the part under examination. The radius of the stylus tip shall have any one of the following values:

a) $r = 0{\cdot}025$ mm,
b) $r = 0{\cdot}250$ mm, or
c) $r = 2{\cdot}50$ mm.

3.3 *Stylus Hatchet Radius* — A moderately sharp edge is desirable so as to wipe away bits of dirt. At the same time the included angle should be great enough to enable the stylus to lift itself readily out of any cracks or slots it may meet round the circumference, and angle of 90° is generally suitable.

3.3.1 The hatchet radius of 1·3 mm may be used for general purpose ball races and hatchet radius of 6 mm may be used for plain cylinders and cones. Generally the tip radius is of the order of 0·25 mm.

3.4 *Stylus Hatchet Width* — The stylus hatchet width shall be such as to mask the effect of primary surface texture, except in special cases where the primary surface texture is also required to be known.

3.5 *Stylus for Measurement of Grooves of Small Radius* — For measurement of grooves of small radius, the stylus width and hatchet radius small be such as to enable contact between the workpiece and the edge of stylus at the centre line.

3.6 *Measuring Force* — Depending upon the material and size of the work piece and for ensuring that the measuring stylus follows the contours of the workpiece surface, the measuring force of the stylus shall be between 10 mN and 200 mN.

4. Assessment of Circularity Error from the Polar Graph — The numerical evaluation of circularity error from the graph is made by drawing two concentric circles, which would just enclose the profile. The radial distance separating the two circles would then give a measure of circularity error of the profile. There are several ways in which these two circles may be drawn. They are given below.

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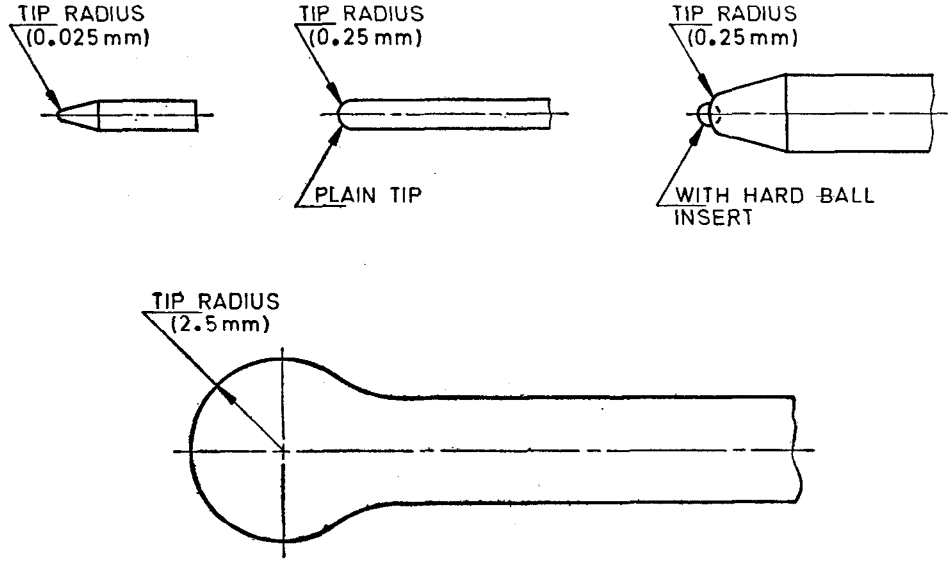
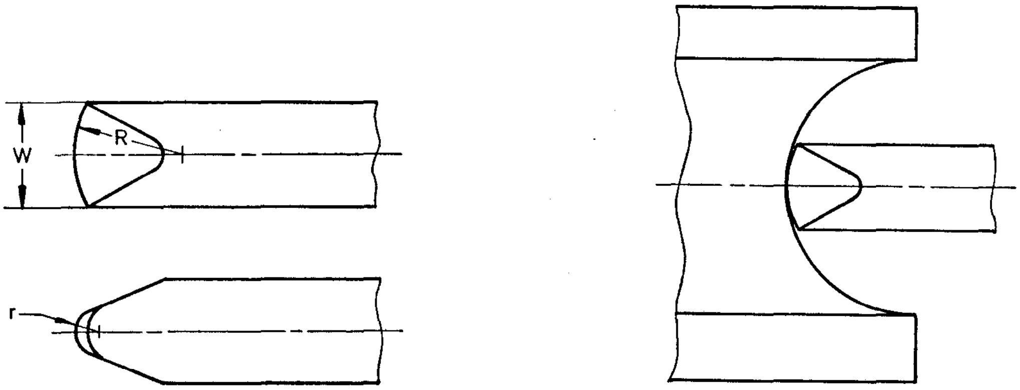


1A Spherical Stylus



W = Stylus hatchet width (1·58 to 2·38 mm)
R = Stylus hatchet radius (12·25 to 25·0 mm)
r = Stylus Tip radius (0·025 to 2·54 mm)

1B Hatchet Stylus

1C Hatchet Stylus in a Groove of Small Radius

FIG. 1 FORMS OF STYLUS TIP (SPHERICAL OR HATCHET FORM)

4.1 *Plug Gauge Centre Method* (PGC) — The basis of this method (*see* Fig. 2A), is the maximum inscribed circle which can be fitted into the trace and the maximum departure of the profile from this circle is assessed by direct measurement through its centre. The error is best interpreted from a largest ideally circular plug gauge that can be passed through the workpiece. In practice, circle of maximum diameter which may just be placed inside the profile trace is first drawn and then a circle concentric to this circle is drawn so that the measured profile is just contained withtin these two circles. This method is recommended for assessing the circularity error of bores. The circularity error is the radial distance between the two circles, through their centre.

4.2 *Ring Gauge Centre Method* (RGC) — The basis of this method (*see* Fig. 2B), is the minimum circumscribing circle containing the trace and the maximum departure of the profile from this circle is assessed by direct measurement through its centre. The error is best interpreted from a smallest ideally circular ring gauge that may be passed over the workpiece. In practice, circle of minimum diameter which may just be placed over the profile trace is first drawn and then a circle concentric to this circle is drawn so that the measured profile is just contained within these two circles. This method is recommended for assessing the circularity error of shafts. The circularity error is the radial distance between the two circles through their centre.

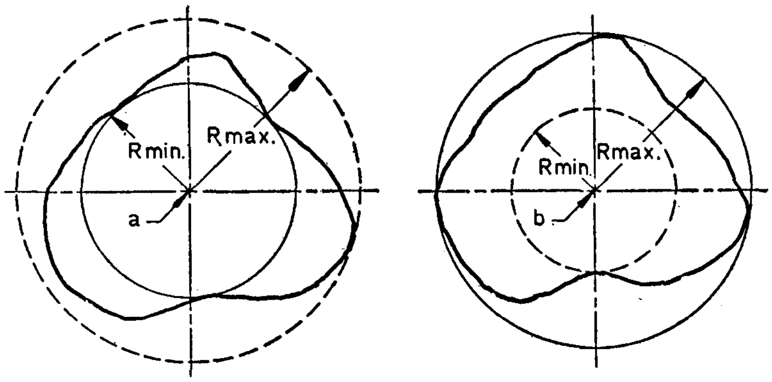
4.3 *Minimum Zone Centre Method* (MZC) — In this method (*see* Fig. 2C), the centre is located in such a way that the radial separation between the two concentric circles drawn from the centre and just containing the measured profile is minimum.

4.3.1 In actual practice the two circles are obtained by trial and error by following a systematic procedure of shifting the centre and drawing two concentric circles enclosing the profile till a minimum radial separation between the two circles is obtained. It may be carried out using compasses or floating transparent template having concentric circles at equal intervals of radius. However, this may be carried out faster in a computer.

4.3.2 The value as per this definition is unique, since a smaller value cannot exist. But because of limitation in techniques to find the MZC, the centre itself need not be unique.

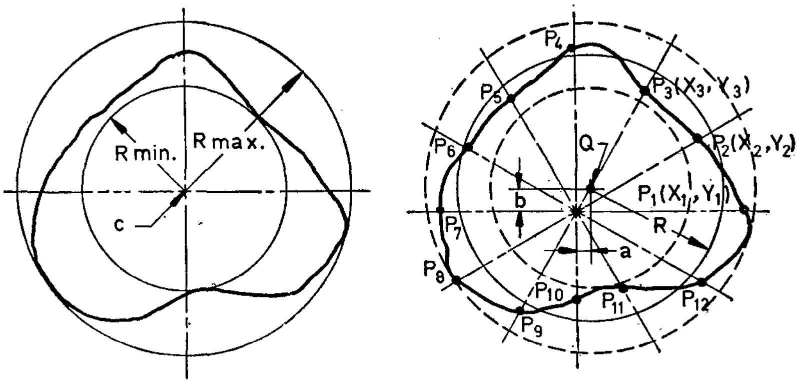
4.3.3 The minimum zone method gives the error according to the definition of circularity error.

4.4 *Least Squares Centre Method* (LSC) — In this method (*see* Fig. 2D), the least squares centre is first found out for the traced profile. It is the centre of a circle having a definite radius and so drawn that the sum of the squares of a sufficient number of equally space radial ordinates measured from this circle to the traced profile has a minimum value. The circle so drawn is called the least squares mean circle. Form the least squares centre two circles are drawn just enclosing the measure profile. The radial distance between these two circles gives the error of circularity. The least squares method is a unique method since this may be easily computerised. The accuracy of evaluation increases with increasing number of ordinates. It is however to be noted, that this is not generally applicable when the periphery of the part under test is interrupted, for example, parts with splines, keyways, etc.



2A Plug gauge centre (PGC) method. Maximum inscribing circle (inner circle) is drawn first and the centre is located.
($R_{Max} - R_{Min}$) = 19·304 mm
Magnification = 5 000 X

2B Ring gauge centre (RGC) method. Minimum circumscribing circle (outer circle) is drawn first and the centre is located.
($R_{Max} - R_{Min}$) = 22·352 mm
Magnification = 5 000 X



2C Minimum zone centre (MZC) method. Found out by trial and error, till the radial difference between the two concentric circles becomes minimum.
($R_{Max} - R_{Min}$) = 18·288 mm
Magnification = 5 000 X

2D Least squares centre (LSC) method. The two concentric circles are drawn from the least squares centre.
($R_{Max} - R_{Min}$) = 19·050 mm
Magnification = 5 000 X

FIG. 2 DIFFERENT METHODS USED FOR EVALUATION OF CIRCULARITY ERROR

4.4.1 The least squares mean circle may be located with respect to the measured profile, by the use of simple approximate formulae given below :

a) If reference is made to points on the measured profile with respect to a co-ordinate system with origin at '0', which is the centre of the polar chart (paper) and if Q is the centre of the least squares mean circle, then the co-ordinates a and b of the least squares centre Q with respect to origin '0' are given by :

$$a = \frac{2 \Sigma xi}{n}$$

$$b = \frac{2 \Sigma yi}{n}$$

where xi and yi are the co-ordinates of the points on the measured profile at which the radial ordinates from the origin '0' intersect it (*see* Fig. 2D).

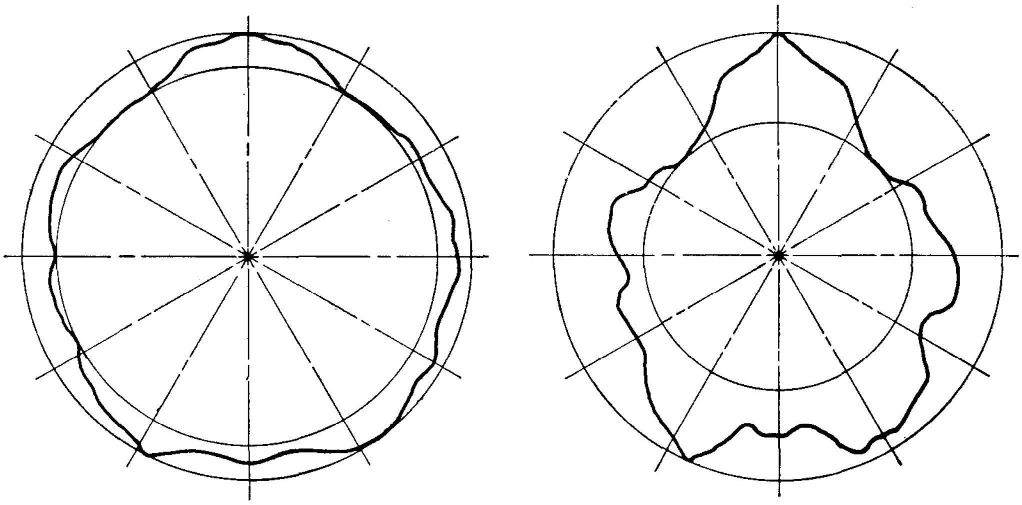
b) The radius R of the least squares mean circle may be obtained as the average of the radial distances of the points on the profile from '0',

$$R = \frac{\Sigma ri}{n}$$

c) In practice, however, it is not necessary to draw the least squares mean circle, and it is sufficient to draw only the inscribing and circumscribing circles from the least squares centre and measure their radial separation.

Note 1 — In practice, all the four methods may be used depending upon the facilities available with the individual instruments. The ring gauge centre method, the plug gauge centre method and the minimum zone centre method of finding out circularity error may be carried out manually on the tracing. The least squares centre method is difficult to carry out manually and requires the use of computer.

Note 2 — Instruments which give the polar graphs of tracing made by the stylus, greatly magnify the radial displacements of the stylus while not making any corresponding magnification of diameter of the workpiece itself. It is thus important to remember that the polar graph gives only the magnified radial variations of the profile from a true circle and not the size. As the magnification is increased, the polar graph of nearly circular profile tends to get distorted. This should be borne in mind while interpreting the polar graphs. The effect of magnification is shown in Fig. 3. The profiles have been recorded at radial magnifications of 4 000 X (*see* Fig. 3A) and 10 000 X (*see* Fig. 3B) respectively.



3A Magnification 4 000 X

3B Magnification 10 000 X

FIG. 3 EFFECT OF MAGNIFICATION ON THE SHAPE OF THE GRAPH

5. Statement of Circularity Error

5.1 *Numerical Values* — Error of circularity shall be expressed in micrometers.

5.2 The following abbreviations shall be used to indicate the centre chosen for the polar graph for evaluating the error of circularity of the workpiece.

a) MZC (Minimum zone centre),

b) LSC (Least squares centre),

c) RGC (Ring gauge centre), and

d) PGC (Plug gauge centre).

5.3 Additional information such as frequency response of the circuit used and the stylus tip radius may be specified when necessary or desirable.

5.4 A circularity error of 5 micrometers by the least squares centre method with an instrument having a response of upto 50 undulations per revolution and a stylus tip radius of 2·5 mm shall be designated as follows :

5 LSC — 50 — 2·5

APPENDIX A

(*Clause* 1)

A-0. Other Methods (Workshop Methods) of Assessing Circularity Error — All the methods described here are point to point measurement and do not give the true value of circularity error.

A-1. Determination by Means of Two Point Measurement (Measurement of Diameter) — As a workshop practice the diameters along various sections in one plane are measured and half the maximum variation in diameter is taken as the circularity error. This method is good for components having even number of lobes or undulations, but in case of odd number of lobes, it will not give a true value of error of circularity.

A-2. Assessment Using Centres — Often, in workshop the error of circularity of a cylidrical workpiece is assessed by mounting it between centres and noting down the maximum variation in dial indicator readings, as the workpiece is rotated and with the indicator plunger contacting the surface of the workpiece. However, it must be realised that the observed variation may be the result of combination of several effects, such as:

a) Circularity error of the section of the workpiece, where the measurement is being carried out;

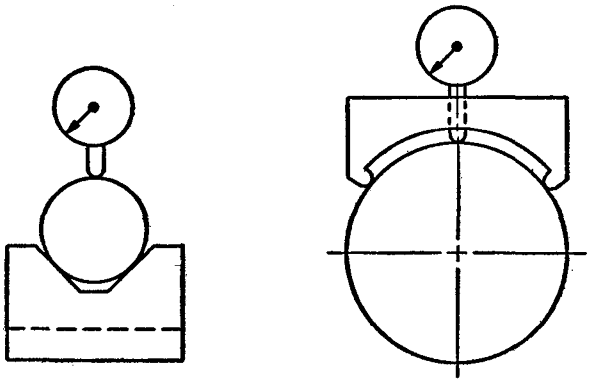
b) Run out of the section with respect to the axis of rotation defined by the centres;

c) Random movements due to circularity errors of contres and centre holes; and

d) Bend in workpiece.

A-2.1 The accuracy of this method, therefore depends upon the magnitudes of the above factors. For this reason this method is not generally recommended unless sufficient care is taken to minimize the errors from the above mentioned sources.

A-3 Assessment Using Vee-Blocks — This is a widely used method and is shown schematically in Fig. 4A. In this method, the cylindrical workpiece is supported on a vee-block and an indicator supported on a stand with its stem vertical, contacts the top surface of the workpiece. When the workpiece is rotated, the indicator gives variations in height with respect to the supporting points of the flanks of vee-block. This method gives precise values provided the undulations are uniform in height and spacing and the angle between the supports is appropriately chosen.



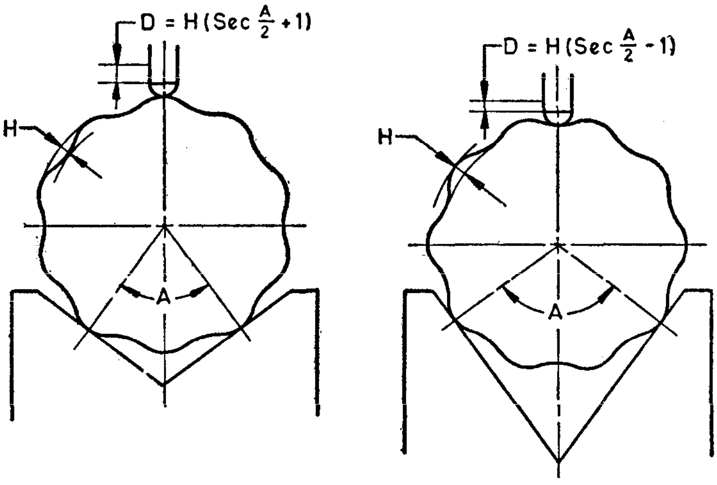
4A Indicator stylus tip position is opposite to position of supports

4B Indicator stylus tip position is in the same direction as positions of supports

FIG. 4 POSITION OF INDICATOR STYLUS TIP WITH RESPECT TO POINTS OF SUPPORT

A-3.1 If the indicator and work supports are in the same transverse plane but on opposite sides of the part as shown in Fig. 4A and assuming repetitive undulations, a preferred angle is the one which gives greatest sensitivity, that is, the maximum indicator variation. This condition is the one for which, crests simultaneously engage the supports as well as the indicator stylus tip (*see* Fig. 5A). The least sensitivity, that is, the lowest variation in dial gauge readings results, when the angle of the vee-block is such that when the crests engage the supports, a valley engages the indicator stylus tip, as shown in Fig. 5B. The relation between the indicator displacement and the radial height of the repetitive undulations is given by the formulae given in the figure itself.

A-3.2 If the indicator and the work supports are arranged on the same side of the part as in Fig. 4B, the optimum angle for vee-block will be the one for which the crests engage the supports when a valley engages the indicator stylus tip. In this position, the variations in readings will be maximum.



5A 5B

Note — Assessment depends upon the angle of vee in relation to the number of undulations of the workpiece.

FIG. 5 ASSESSMENT USING VEE-BLOCKS

A-3.3 When the undulations are irregular in height and in spacing, the vee-block method does not give accurate results. In such a case, it is not possible to have any formula for the conversion of the results obtained from vee-block measurement to the results obtained by the methods described in this standard.

A-3.4 In spite of these limitations, the vee-block method is still used in workshops because of its simplicity of usage, and if proper selection of angle of vee-block is made and appropriate correction factors are applied, the method gives sufficiently accurate results. It is recommended to carry out the measurement using two or three vee-blocks, having different angles, to ascertain which angle gives the maximum variation, so that the correction factor can be correspondingly selected. The value of the dial indicator variation should be divided by the correction factor to get value of the circularity error. The optimum angles of vee-block and the correction factors to be applied, for different odd number of lobes are given in Table 1. The optimum angle of vee-block can be found out from the formula, $\theta = 180° - \frac{360°}{n}$ where n is the number of uniformly spaced undulations around the component surface and θ is the angle of vee-block.

Example :

when $n = 3$, $\theta = 60°$;
when $n = 5$, $\theta = 108°$; and
when $n = 7$, $\theta = 128° 34$.

TABLE 1 OPTIMUM ANGLES OF VEE-BLOCK AND CORRECTION FACTORS TO BE APPLIED FOR THE MEASURED VALUE

Number of Lobes on the Component	Optimum Angle of Vee-Block	Correction Factor
3	60°	3·00
5	108°	2·24
7	128°34′	2·11
9	140°	2·06

Example :

If the dial indicator shows a maximum TIR of 9μm, when a component having 3 lobes, is checked on a Vee-block of 60°, the actual value of circularity will be $\frac{9}{3} = 3\mu m$ where 3 is the correction factor.

EXPLANATORY NOTE

In the preparation of this standard, considerable assistance has been derived from BS 3730 : 1964 ' Methods for the assessment of departures from roundness ', issued by the British Standards Institution and Draft ISO Recommendation ISO/TC 57/SC 3-2E, May 1973 ; 'Methods for the assessment of departures from roundness', issued by the International Organization for Standardization.

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